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MARKED UP SUBSTITUTE SPECIFICATION

TITLE OF THE INVENTION

METHOD AND SYSTEM FOR RECEIVING MULTICARRIER SIGNALS HAVING A NUMBER OF FREQUENCY-DISCRETE SUBCARRIERS

BACKGROUND OF THE INVENTION

1. Field of the Invention

[0001] The present invention is directed to wireless communications networks, based on radio channels, in particular in point-to-multipoint radio feeder networks.

2. Description of the Related Art

[0002] In wireless communications networks, based on radio channels, in particular in point-to-multipoint radio feeder networks - also referred to as "Radio In The Local Loop" or "RLL" - a number of network termination units are each connected via one or more radio channels to a base station - also referred to as "Radio Base Station" or "RBS". For example, a wireless feeder network for wireless voice and data communication is described on pages 36, 37 of telecom report No. 18 (1995), Issue 1 "Drahtlos zum Freizeichen" which means "Wireless for Calling". The described communications system is an RLL subscriber access in conjunction with a modern broadband infrastructure - for example "Fiber to the curb" - which can be implemented in a short time and without major effort, instead of laying wire-based connecting cables. The network termination units RNT associated with the individual subscribers are connected via the "radio channel" transmission medium and the base station RBS to a higher-level communications network, for example to the ISDN-oriented landline network.

[0003] The increasingly widespread use of multimedia applications means that high-bit-rate data streams have to be transmitted quickly and reliably via communications networks, in particular via wireless communications networks and via mobile radio systems, with the radio

transmission systems, which are based on a "radio channel" transmission medium which is susceptible to disturbances and whose transmission quality is difficult to assess, being subject to stringent requirements. One transmission method for transmitting broadband data streams - for example video data streams - is, for example, the OFDM transmission method which is based on a multicarrier method - also referred to as Orthogonal Frequency Division Multiplexing OFDM. In the OFDM transmission technique, the information to be transmitted or the data stream to be transmitted is subdivided or parallelized between a number of subchannels or subcarriers within the radio channel, with the information to be transmitted in each case being transmitted at a relatively low data rate, but in parallel in an additively superimposed form. The OFDM transmission technique is used, for example, for digital terrestrial broadcast radio - also referred to as Digital Audio Broadcasting DAB - and for digital terrestrial television - also referred to as Digital Terrestrial Video Broadcasting DTVB. In particular, the OFDM transmission technique is intended to be used in future wireless local communications networks - also referred to as Wireless LAN or WLAN - and in future mobile radio communications networks - for example UMTS. The OFDM transmission technique will also be used in future access methods such as MC-SSMA - Multi-Carrier Spread Spectrum Multiple Access - or MC-CDMA - Multi-Carrier CDMA.

[0004] The OFDM transmission method is described in more detail in Figure 6 on page 46 of the document "Mitteilungen der TU-Braunschweig, Mobilfunktechnik für Multimedia-Anwendungen", Professor H. Rohling, Year XXXI, Issue 1-1996, the title of which means "Reports from Brunswick Technical University, Mobile Radio Technology for Multimedia Applications". In this case, based on a serial datastream in the transmitter, serial/parallel conversion is carried out for modulation of the, for example, n subcarriers, with a binary code word with a word length k - the word length k is dependent on the modulation method used - being formed in each case for the i-th OFDM block in time with the block length T' and the j-th

subcarrier. A transmitter-specific modulation method is used to form the corresponding complex modulation symbols - also referred to as transmission symbols in the following text - from the code words that have been formed, with a transmission symbol being allocated to each of the k subcarriers at each time i. The separation between the individual subcarriers is defined by Δf = 1-T', thus guaranteeing the orthogonality of the individual subcarrier signals in the interval (0,T') that is used. The oscillations of the individual subcarriers are multiplied by the corresponding modulation symbols or transmission symbols, and the modulation products that are formed are then added, to produce the corresponding time-discrete transmission signal for the i-th OFDM block in time. This transmission signal is calculated directly from the modulation symbols or transmission symbols of the individual subcarriers under consideration by Inverse, Discrete Fourier Transformation - IDFT. In order to minimize intersymbol interference, each OFDM block is preceded by a guard interval T_G in the time domain which results in the time-discrete OFDM signal being lengthened in the interval ($-T_G$, 0) - see "Mitteilungen der TU-Braunschweig, Mobilfunktechnik für Multimedia-Anwendungen", which means "Report from Brunswick Technical University, Mobile Radio Technology for Multimedia Applications," Figure 7. The guard interval T_G that is inserted advantageously corresponds to the maximum delay time difference that occurs between the individual propagation paths which occur during radio transmission. The removal of the added guard interval T_G at the receiver end avoids, for example, any interference between the i-th OFDM block and the OFDM signal which is adjacent in time at the time i-1, so that the transmission signal is received over all the circuitous paths in the interval (0,T'), and the orthogonality is fully maintained between the subcarriers in the receiver. If there are a large number of subcarriers - for example n = 256 subcarriers - and the symbol durations $T = T' + T_G$ are correspondingly long, then the duration T_G is short in comparison to T, so that the insertion of the guard interval efficiently has no significant adverse effect on the bandwidth, and the resultant overhead is only small. After sampling of the transmission signal, received at the input of the receiver in baseband - by an A/D converter -

and after extraction of the interval being used - that is to say after removal of the guard interval T_G - a Discrete Fourier Transformation - DFT - is used to transform the received transmission signal to the frequency domain, that is to say the received modulation symbols and the received symbols are established. A suitable demodulation method is used to produce the corresponding received code words from the established received symbols and the received serial datastream is formed by parallel/serial conversion from these code words. The avoidance of intersymbol interference when using OFDM transmission methods considerably reduces the computation effort in the respective receiver, as a result of which the OFDM transmission technique is used, for example, for terrestrial transmission of digital television signals - for example for transmission of broadband datastreams at a transmission rate of 34 Mbps per radio channel.

[0005] Absolute or differential modulation methods and corresponding coherent or incoherent demodulation methods are used for transmission of the serial datastream to be transmitted using the OFDM transmission method. Examples of an absolute modulation method include 4-QAM or 16-QAM - Quadrature Amplitude Modulation. Although the orthogonality of the subcarriers is fully maintained when the OFDM transmission method is used to transmit the transmission signal that has been formed via the only "radio channel" transmission medium, the transmission characteristics of the radio channel result in the transmitted, frequency-discrete or frequency-selective transmission symbols being varied both in phase and amplitude. The amplitude and phase influence of the radio channel affects the individual subcarriers, which each have a very narrow bandwidth, on a subcarrier-specific basis; furthermore, noise signals are additively superimposed on the transmitted user signal. When using coherent demodulation methods, channel estimation is required which, depending on the quality requirements, involves a considerable technical and financial implementation penalty and, furthermore, reduces the performance of the transmission system. It is advantageous to use differential modulation methods and corresponding incoherent demodulation methods in which there is no need for

complex radio channel estimation. In differential modulation methods the information to be transmitted is not transmitted directly by selection of the modulation symbols or of the frequency-discrete transmission symbols, but by changing the frequency-discrete transmission symbols, which are adjacent in time, on the same subcarrier. Examples of differential modulation methods include 64-step 64-DPSK - Differential Phase Shift Keying - and 64-DAPSK - Differential Amplitude and Phase Shift Keying. In 64-DAPSK, both the amplitude and the phase are differentially modulated at the same time.

[0006] If there are major delay time differences between the individual signal paths, that is to say when severe multi-path propagation occurs, different attenuation levels, dependent on the transmission channel, with attenuation differences of up to 20 dB or more, may occur between the individual received subcarriers. The received subcarriers having high attenuation levels, or subcarriers with low S/N ratios - also referred to as the signal power-to-noise power ratio - have a very high symbol error rate, as a result of which the overall bit error rate over all the subcarriers rises considerably. In the case of subcarriers modulated using coherent modulation methods, it is already known for the attenuation losses caused by the frequency-selective transmission characteristics of the transmission medium - also referred to as the transfer function H(f) - to be corrected at the receiving end by using the inverse transfer function - also referred to as 1/H(f), with the frequency-selective attenuation losses being determined, for example, by evaluating transmitted reference pilot tones, which are each associated with specific subcarriers.

[0007] Normally, OFDM signals arriving at a receiver are mixed down to the intermediate frequency band or baseband by a local oscillator in a radio-frequency unit - also referred to as an RF frontend.

[0008] The respective local oscillators at the transmitting end and at the receiving end, have different frequency fluctuations and different phase noise depending on the quality and the Q factor. OFDM signals in particular are highly susceptible to frequency fluctuations and phase noise, which are produced in particular in low-cost LO oscillators, so they result in loss of the orthogonality between the adjacent subcarriers in the frequency domain. The phase noise from a local oscillator causes disturbances in the demodulated baseband signal resulting, in particular, in the production of a Common Phase Error - also referred to as CPE interference or disturbances - and "Inter Carrier Interference" - also referred to as ICI disturbances in the baseband signal.

[0009] CPE disturbances rotate all the subcarriers in an OFDM received signal through a constant phase difference, in which case the phase difference can be estimated, and the OFDM signal can be corrected accordingly, with minimal effort. On the other hand, ICI disturbances cause mutual interference between the adjacent subcarriers in the frequency domain, with the respective extent of such disturbances being dependent on the nature of the information being transmitted. ICI disturbances are produced in the convolution of the individual subcarriers with the local oscillator carrier signal, which is subject to phase noise. If the same information is transmitted on each subcarrier, the same ICI interference is additively superimposed on each subcarrier. During normal operation, each subcarrier is subject to different amplitude fluctuations, which result in different ICI disturbances being produced in the individual subcarriers, depending on the modulation method being used and on the data being transmitted. The received OFDM signal is a complicated additive superimposition of a very large number of signal elements, so that the ICI interference can be established directly only by increased effort.

[0010] Oscillators with low phase noise - also referred to as pure phase oscillators - are available, but these are either very expensive or have a minimal trimming range, and which thus require complex additional baseband circuits.

SUMMARY OF THE INVENTION

[0011] The invention is based on the object of designing a low-cost way of transmitting information using a multicarrier method and, in particular, of achieving effective utilization of the transmission resources available in the transmission medium.

[0012] In the method according to the invention for receiving a multicarrier signal having a number of frequency-discrete subcarriers, the information to be transmitted is converted by a multicarrier method to frequency-discrete modulation symbols, and is inserted into the multicarrier signal. The individual frequency-discrete subcarriers of the multicarrier signal transmitted via a transmitter medium are each subject to subcarrier-specific disturbances caused by adjacent subcarriers in the frequency domain. The major aspect of the method according to the invention is that the subcarriers in the received multicarrier signal are additionally deliberately subjected to test disturbances. The modulation symbols contained in the deliberately disturbed multicarrier signal are compared with undisturbed modulation-specific modulation symbols, and subcarrier-specific error information is derived from the comparison results. Correction information which represents subcarrier-specific disturbances is derived as a function of the predetermined test disturbances and as a function of the derived subcarrier-specific error information. The subcarriers in the received multicarrier signal are corrected in accordance with the determined correction information.

[0013] The major advantage of the method according to the invention is that the compensation according to the invention for the subcarrier-specific disturbances or ICI

disturbances contained in the received multicarrier signal means that particularly low-cost local oscillators can be used in the respective transmitting and receiving devices. Such oscillators may, for example, be based on gallium arsenide and can be produced with the minimum financial cost and technical complexity using Monolithic Microwave Integrated Circuit (MMIC). Furthermore, no additional insertion of redundant information is required at the transmission end for estimation of the ICI disturbances or to establish correction information in order to implement the method according to the invention, thus allowing effective utilization of the transmission resources available in the transmission medium to be achieved.

[0014] The received symbols which represent frequency-discrete subcarriers are advantageously derived from the received multicarrier signal. In this advantageous refinement, k differently defined reference disturbance information items are provided, in which case, for each reference disturbance information item, the received symbols in the subcarriers which are in each case adjacent to at least some of the subcarriers in the frequency domain are each subjected to disturbances from the reference disturbance information, and the disturbed received symbols in the adjacent subcarriers are then additively superimposed (a) as deliberate test disturbances on the received symbol in the additionally disturbed subcarrier. The additionally deliberately disturbed received symbols are each compared with the closest modulation-specific modulation symbol, and subcarrier-specific error information is formed (b) as a function of the comparison results, and disturbance-information-specific sum error information is formed (c) from the subcarrier-specific error information. The k reference disturbance information items and the k sum error information items are then used to derive (d) the correction information . This advantageous refinement allows the correction information for estimating the ICI disturbances to be established very accurately, since the correction information has been derived by averaging over all the subcarriers in the received multicarrier signal.

[0015] According to one advantageous refinement of the method according to the invention, the correction information (ici_{opt}) is determined in the course of an iterative search, with the k reference disturbance information items (ici1...4) being established in the course of the iterative search, and steps (a) to (c) being repeated until a minimum value of the disturbance-information-specific sum error information (ε_{min}) is determined, and the correction information (ici_{opt}) has been derived from this . Determination of correction information (ici_{opt}) using the iterative search represents a highly stable method.

[0016] According to a further advantageous refinement of the method according to the invention, the additionally deliberately disturbed received symbols are in each case corrected by equalization as a function of frequency-selective transmission characteristics of the transmission medium before the comparison with the respective closest modulation-specific modulation symbol. Equalizing the received multicarrier signal to correct for the frequency-selective transmission characteristics of the transmission medium means that any errors which may have occurred in the comparison of the deliberately disturbed received symbols with the respective closest modulation-specific modulation symbols are minimized, and the quality of the determined correction information is thus improved.

[0017] Advantageously, once steps (a) to (d) have each been carried out for each reference disturbance information item the received symbols of the subcarriers which are each further away from at least some of the subcarriers in the frequency domain are each subjected to disturbances from the reference disturbance information, and the disturbed received symbols are then additively superimposed as deliberate test disturbances on the received symbol of the additionally disturbed subcarrier (a'). Steps (b) to (d) are then carried out. Giving additional consideration to those subcarrier-specific disturbances which are in each case caused by adjacent carriers that are further away in the frequency domain further improves the quality of the determined correction information.

[0018] In order to achieve a further improvement in the process of establishing the correction information, according to a further advantageous refinement of the method according to the invention, the received symbols which have been corrected using the correction information are demodulated. Errors are identified in the demodulated received symbols using error identification information inserted into the transmitted information, and identified, erroneous received symbols are corrected. When errors are identified, steps (b) to (d) are carried out once again, with the corrected received symbols being used for determining the correction information.

[0019] Further advantageous refinements of the method and system according to the invention for receiving a multicarrier signal having a number of frequency-discrete subcarriers are described below.

BRIEF DESCRIPTION OF THE DRAWINGS

[0020] The method according to the invention will be explained in more detail in the following text with reference to four drawings, in which:

Figure 1 is graph of a disturbance model on which the method according to the invention is based, which is used to illustrate the mutual subcarrier-specific interference between subcarriers in a multicarrier signal which are adjacent in the frequency domain,

Figure 2 is a block diagram of a circuit using the method according to the invention,

Figure 3 is a block diagram of an advantageous refinement of a circuit for additive superimposition of reference disturbance information, and test disturbances derived from it, on the respective subcarriers in a received multicarrier signal, and

Figure 4 is a graph of an error curve or correction function from which the correction information to minimize the subcarrier-specific disturbances in a received multicarrier signal is derived.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0021] Figure 1 is graph of a disturbance model, in the frequency domain, to illustrate the problem on which the method according to the invention is based. The disturbance model shows, in detail form, a number of subcarriers st_{i-1}, st_i, st_{i+1} in a multicarrier signal ms which has, in particular, n subcarriers st1...n and is formed using a multicarrier method. It is assumed in the following text that the multicarrier signal is produced using an OFDM transmission method. Originating from each subcarrier st_i, subcarrier-specific disturbances icix are produced in those subcarriers st_{i-1} and st_{i+1} which are adjacent in the frequency domain, and these disturbances are indicated by small arrows in the disturbance model. Conversely, the centrally arranged i-th subcarrier st_i is influenced by the subcarrier-specific disturbances - indicated by $icix_{-1}$ and $icix_{+1}$ in Fig. 1 - caused by the two adjacent subcarriers st_{i-1} and st_{i+1}, with the respective i-th subcarrier st_i in each case having the subcarrier-specific disturbances $icix_{-1}$, $icix_{+1}$ which are produced actively superimposed on it. As shown in Fig. 1, the received multicarrier signal ms is a complicated superimposition of a very large number of signal elements, so that it is no longer possible to establish directly the subcarrier-specific disturbances icix originating from the individual subcarriers st1...n.

[0022] Figure 2 is a block diagram of a circuit in a receiving unit E and by which the subcarrier-specific disturbances icix - also referred to as ICI disturbances in the following text - contained in the received OFDM signal ms are estimated, with the received OFDM signal ms then being corrected by equalization as a function of the estimation result. The block diagram shows a receiving unit E which has a receiving antenna A and may, for example, be a modular component in base stations or network termination units, which act as receiving systems in wireless communications networks. A radio-frequency converter unit HFU is connected via an input EH to the receiving antenna A which is fitted externally on the receiving unit E. A local oscillator LO in the radio-frequency converter unit HFU has oscillator-specific phase noise φ_{LO}. The radio-

frequency converter HFU is connected via an output AH to an input EW of a converter unit WAS. The converter unit WAS performs analog/digital conversion and subsequent serial/parallel conversion (A/D, S/P) of an incoming received signal ms'. The converter unit WAS has n outputs AW1...n, which are connected to corresponding inputs EF1...n of a transformation unit FFT for carrying out a discrete "Fast Fourier Transformation". The transformation unit FFT is connected via n outputs AF1...n to corresponding inputs EP1...n of a parallel/serial converter PSW.

[0023] The parallel serial converter PSW is connected via an output AP to one input ER of each of four parallel-arranged reference modules RM1...4, by which four defined disturbance signals, or reference disturbance information items ici1...4 representing them, are added to the received OFDM signal ms. To do this, each of the four reference modules RM1...4 has a disturbance unit STE, each of which is associated with one of the reference disturbance information items ici1...4, and by which the individual subcarriers st1...n in the received OFDM signal ms have the respectively associated reference disturbance information ici1...4 additively superimposed on them. Each reference module RM1...4 also has an equalizer unit EZ for linear equalization of the received OFDM signal for the radio channel characteristics H(f), and an error detector unit FE in order to establish disturbance-information-specific sum error information sε1...4. Each error detector unit FE is connected via an output AF to an output AR of the respective reference module RM1...4. Each of the four reference modules RM1...4 is connected via the output AR to an input EA1...4 of an evaluation unit ASW.

[0024] The output AP of the parallel/serial converter PSW is also connected to an input EV of a delay unit VE, which delays the received OFDM signal ms by a predetermined time constant Δτ. The delay unit VE is connected via an output AV to the input EK of correction unit KE. The correction unit KE has a control input SE, which is connected to a control output SA of the evaluation unit ASW. The correction unit ~~AE~~ KE is connected via an output AK to an input EE of

a further equalizer unit EZ, which is connected via an output AE to an input ~~AD~~ ED of a demodulator DMOD. The demodulator DMOD has an output AD, to which the demodulated received signal is passed on as a digital data signal di.

[0025] The method according to the invention will be explained in the following text with reference to the circuit illustrated in Fig. 2.

[0026] In a transmitter which is not illustrated, a multicarrier method, for example, an OFDM transmission method, is used to convert the information to be transmitted, by a phase-modulating modulation method - for example 4QAM or 16QAM - to corresponding modulation symbols, which are then converted to an OFDM signal ms, which has a number of frequency-discrete subcarriers st1...n, and this is transmitted via the "radio channel" transmission medium FK to the receiving unit E. The radio channel FK has frequency-selective transmission characteristics H(f), which distort the amplitude and phase of the OFDM signal ms. The transmitted OFDM signal ms is received via the receiving antenna A, which is mounted externally on the receiving unit E, and is supplied to the radio-frequency converter unit HFU. The received OFDM signal ms is down-mixed to the intermediate-frequency band by the local oscillator LO in the radio-frequency converter unit HFU, with the phase noise φ_{LO} in the local oscillator LO producing the subcarrier-specific disturbances icix in the individual subcarriers st1...n in the received OFDM signal ms. The OFDM signal ms' which has been down-mixed to the intermediate-frequency band, is analog/digital converted by the converter unit WAS, and is then parallelized by serial/parallel conversion to corresponding n-time-discrete samples zs1...n which represent the digital OFDM signal. The discrete "Fast Fourier Transformation" that is carried out in the transformation unit FFT is used to calculate the corresponding n received symbols es1...n from the n time-discrete samples zs1...n, and these are then converted by the parallel/serial converter PSW to a serial datastream es1...n. It should be noted that the serial/parallel and parallel/serial converter illustrated in Fig. 2 is not absolutely essential, since

many modern microprocessors already process the incoming and outgoing information in serial form in order to carry out the "Fast Fourier Transformation". The received symbols es1...n which are each passed to the output ~~AW~~ AP of the parallel/serial converter PSW and represent the currently received subcarriers st1...n in the received OFDM signal ms, are each supplied to the four reference modules RM1...4.

[0027] The operation of the reference modules RM1...4 will be explained in more detail in the following text.

[0028] The disturbance units STE in the reference modules RM1...4 are used in each case to superimpose reference disturbance information ici1...4, which represents subcarrier-specific disturbances icix, on the transmitted received symbols es1...n. To this end, using the reference disturbance information ici1...4, subcarrier-specific disturbances $icix_{-1}$, $icix_{+1}$ - also referred to as defined test disturbances - are derived from the respective subcarriers st_{i-1}, st_{i+1} adjacent to an i-th subcarrier st_i, for example by multiplication by the reference disturbance information ici1...4 - and the two derived test disturbances $icix_{-1}$, $icix_{+1}$, are then additively superimposed on the centrally arranged i-th subcarrier st_i.

[0029] By way of example, Fig. 3 shows a circuitry embodiment of the disturbance unit STE for forming the test disturbances icix and for additively superimposing the test disturbances icix that are formed on the subcarriers st1...n. The disturbance unit STE has three timers T1...3, which are used to delay the received symbols es1...n, which arrive in serial form and represent the individual subcarriers st1..n. Arranging the three timers T1...3 in series means that three subcarriers st_{i-1}, st_i and st_{i+1}, which are adjacent in the frequency domain and are represented by the received symbols es1...n, are in each case available at the same time. The first and the third timer T1, T3 are each connected via an output AT to an input EM of a multiplier M, which is used to multiply the respective received symbol es1...n currently stored in the corresponding

timer T1, T3 by the reference disturbance information ici1...4 associated with the respective reference module RM1...4. The two multipliers M are connected via in each case one output AM to inputs EA of an adder ADD, to which an output AT of the second timer T2 is also connected. The circuit illustrated in Fig. 3 is used to multiply the respective subcarriers st_{i-1}, st_{i+1}, which are adjacent about an i-th subcarrier, or the received symbols es1...n representing them by the respectively associated reference disturbance information ici1...4, and the two multiplication products which each represent test disturbances $icix_{-1}$, $icix_{+1}$ added to the i-th subcarrier st_i, or to the received symbol es1...n representing it. Depending on the respective mathematical sign of the individual reference disturbance information items ici1...4, the test disturbances $icix_{-1}$, $icix_{+1}$ which are formed are added to or subtracted from the respective i-th subcarrier st_i, which the disturbance process which is illustrated in Fig. 1, based on the phase noise φ_{LO} of the local oscillator LO in the radio-frequency converter unit HFU being reversed by the subtraction of a test disturbance icix.

[0030] In order to allow the ICI disturbances ici0 caused by the phase noise in the oscillator LO to be established or estimated accurately, the received symbols es'1...n to which the various reference disturbance information items ici1...4 have been applied are also linearly equalized by the equalizer unit EZ. In order to allow linear equalization to correct for the transmission characteristics of the transmission medium, the transfer function H(f) of the radio channel FK is established, for example using pilot symbols. The received symbols es'1...n are then multiplied by the inverse transfer function 1/H(f). The equalized received symbols es"1...n are then supplied to the error detector unit FE.

[0031] In the error detection unit FE, the received symbols es"1...n supplied to it are each compared with the next-best or most probable modulation symbol - the set of modulation symbols is in each case dependent on the modulation method used - and the subcarrier-specific error information item $\Delta\varepsilon$1..n is formed for each received symbol es"1...n representing the

difference or the interval between the received symbol es"1...n and the next-best modulation symbol. The subcarrier-specific error information items $\Delta\varepsilon 1..n$ determined for each reference disturbance information item ici1...4 over all the subcarriers st1...n are then added to form a disturbance-information-specific sum error information item $s\varepsilon 1...4$, where $s\varepsilon 1...4 = \sum|\Delta\varepsilon 1...n|$. The four disturbance-information-specific sum error information items $s\varepsilon 1...4$ defined in the four reference modules RM1...4 are each passed on to the evaluation unit ASW.

[0032] In the evaluation unit ASW, correction information ici_{opt} is derived, in accordance with the error curve illustrated in Fig. 4, from the four predetermined reference disturbance information items ici1...4 and from the four disturbance-information-specific sum error information items $s\varepsilon 1...4$ defined in the four reference modules RM1...4. The error curve at the same time represents a correction function and is illustrated in a two-dimensional coordinate system, with the reference disturbances ici1...4, or the test disturbances icix derived from them, being plotted on the abscissa, and the respectively defined, disturbance-information-specific sum error information items $s\varepsilon 1...4$ being shown on the ordinate - where $s\varepsilon 1...4 = \sum|\Delta\varepsilon 1...n(ici1...4)|$. For the exemplary embodiment it is assumed that the sums of the respective subcarrier-specific error information items $\Delta\varepsilon 1...n$, that is to say the disturbance-information-specific sum error information items $s\varepsilon 1...4 = \sum|\Delta\varepsilon 1...n|$, rise linearly as the ICI interference increases, that is to say as the magnitudes of the reference disturbance information items ici1...4 rise, since the disturbance model illustrated in Fig. 1 is based on additive disturbance terms. Ideally, when a multicarrier signal ms is received without any ICI interference, the sum of the subcarrier-specific error information items $\Delta\varepsilon 1...n$ has a minimum value $s\varepsilon_{min}$ with the minimum value $s\varepsilon_{min}$ turning to zero in an ideal communications system, without any additively superimposed Gaussian noise - AWGN - and without any estimation error $\Delta H(f)$ for the radio channel FK. In real systems, the minimum value $s\varepsilon_{min}$ has a value that is not

equal to zero. Due to the phase noise from the local oscillator LO in the radio-frequency-converter unit HFU, the received symbols es1...n which are produced at the output of the parallel/serial converter PSW have ICI interference which cannot be recorded precisely, and which is represented by the value ici0 in Fig. 4. Based on this ICI interference ici0, which cannot be measured, this results in subcarrier-specific error information $\Delta\varepsilon 1...n$, whose sum $\sum|\Delta\varepsilon 1...n|$ gives the value $s\varepsilon 0$, which is likewise shown in Fig. 4, where $s\varepsilon 0 \geq s\varepsilon_{min}$.

[0033] Figure 4 shows the intersection of the ICI interference ici0 which is contained in the received symbols es1...n but cannot be established with any great accuracy, and the sum, resulting from this, of the subcarrier-specific error information $s\varepsilon 0 = \sum|\Delta\varepsilon 1...n(ici0)|$ by a point AP. Starting from this point, or this point of origin AP, the received symbols es1...n each have the four different reference disturbance information items ici1...4 or test disturbances icix applied to them in the described manner according to the invention - in the respective reference modules RM1...4- and the disturbance-information-specific sum error information items $s\varepsilon 1...4$ are then determined. As shown in Fig. 4, the first and the third reference disturbance information items ici1,3 each represent a very low level of ICI interference in each case with the opposite mathematical sign, while the second and the fourth reference disturbance information items ici2,4 each represent a relatively high ICI interference level. A linear relationship is assumed between the reference disturbance information ici1...4, or the disturbance signals icix derived from them, and the disturbance-information-specific sum error information items $s\varepsilon 1...4$ resulting from them. The linear relationship is indicated in the error curve or correction function illustrated in Fig. 4 by a linear characteristic $\sum|\Delta\varepsilon 1...n|$ whose gradient is S. By calculating the gradient S of the correction function, it is possible to establish from the known output variables - in this case from the reference disturbance information items ici1...4 - and the disturbance-information-specific sum error information items $s\varepsilon 1...4$ established with the aid of the reference modules RM1...4, that correction information item ici_{opt} which gives the sum of the subcarrier-

specific error information items $\sum|\Delta\varepsilon 1...n(ici_{opt})|$ the minimum value $s\varepsilon_{min}$; that is to say the specific correction information item ici_{opt} can be used to produce that disturbance icix which minimizes the ICI interference present in the received OFDM signal.

[0034] The correction information can be derived from the known variables using the following calculation rule:

$$s\varepsilon_0 = \frac{(s\varepsilon 1 + s\varepsilon 3)}{2} \quad (1)$$

$$\Delta s\varepsilon = \frac{(s\varepsilon 1 - s\varepsilon 3)}{2} \quad (2)$$

$$S = \frac{\Delta s\varepsilon}{ici3} = \frac{s\varepsilon 1 - s\varepsilon 3}{ici1 - ici3} \quad (3)$$

$$s\varepsilon_{min} = s\varepsilon_0 + S \bullet ici_{opt} \quad (4)$$

$$s\varepsilon 4 = s\varepsilon_{min} - S \bullet (ici4 - ici_{opt}) \quad (5)$$

It follows from equations (1) to (5) that:

$$ici_{opt} = \left(\frac{s\varepsilon 4 - s\varepsilon 0}{2(s\varepsilon 1 - s\varepsilon 3)}\right) \bullet (ici1 - ici3) + \frac{ici4}{2} \quad (6)$$

$$ici_{opt} = \left(\frac{s\varepsilon 4 - \frac{(s\varepsilon 1 + s\varepsilon 3)}{2}}{2(s\varepsilon 1 - s\varepsilon 3)}\right) \bullet (ici1 - ici3) + \frac{ici4}{2} \quad (7)$$

where $ici1, ici2 \geq 0$

$ici3, ici4 \leq 0$

[0035] If the point of origin AP (ici0, sε0) is in the left-hand section of the error curve or correction function $\sum|\Delta\varepsilon 1...n|$, or in the second quadrant of the coordinate system, the calculation rule shown above must be adapted appropriately. The effort for calculating the

correction information ici_{opt} is negligible since it is calculated only once after receiving an OFDM signal - after establishing the received symbols es1...n.

[0036] The calculated correction information ici_{opt} is passed on to the correction unit KE. The received OFDM signal ms and the received symbols es1...n produced at the output of the parallel/serial converter PSW are delayed in the delay unit VE by the time constant $\Delta\tau$, with the magnitude of the time constant $\Delta\tau$ being such that the received symbols es1...n are not transmitted to the correction unit KE until the correction information ici_{opt} has been calculated and passed on to the correction unit KE. In the correction unit KE, the delayed received symbols ves1...n have the optimized disturbance icix additively superimposed on them, and are thus corrected, in the manner already described. The corrected received symbols ves'1...n are then multiplied in the equalizer unit EZ by the inverse of the transfer function 1/H(f) of the radio channel FK, and are passed on to the demodulator DMOD. In the demodulator DMOD, the equalized received symbols ves"1...n are demodulated, and are converted to a digital datastream di.

[0037] If the ICI interference level in the received OFDM signal is very high, then, according to one advantageous development of the method according to the invention, the ICI interference caused between subcarriers that are further away - for example between the subcarriers st_{i-2}, st_i and st_{i+2} is also corrected by equalization. An interactive method could be used for this purpose, in which, in a first step, those subcarriers which are immediately adjacent in the frequency domain - in this case the subcarriers st_{i-1}, st_i and st_{i+1} - are corrected by equalization in the described manner. In a second step in the same method, the ICI interference caused by those subcarriers which are further away in the frequency domain - in this case the subcarriers st_{i-2}, st_i and st_{i+2} - is corrected by equalization. If necessary, the iteration method can also be extended to subcarriers st_{i-b}, st_i and st_{i+b}, where $b > 1$, which are further away in the frequency domain.

[0038] Furthermore, if the ICI interference level is very high, the received symbols es1...n may have very large symbol errors. When these received symbols es1...n which are subject to errors are compared with the respectively next-best modulation symbol representing the nominal value - also referred to as the estimated value - the received symbols es1...n may be compared with the wrong modulation symbol, which would lead to considerable errors in the calculation of the sum of the carrier-specific error information items $\sum|\Delta\varepsilon 1...n|$. Incorrect correction information ici_{opt} would be derived from the incorrectly determined disturbance-information-specific sum error information items $s\varepsilon 1...4 = \sum|\Delta\varepsilon 1...n|$. In the worst case, this would cause an increase in the bit errors in the demodulated datastream di.

[0039] According to a further advantageous refinement of the method according to the invention, ~~- not illustrated -~~ an error handling routine - also referred to as Forward Error Correction, FEC - is provided as illustrated in Fig. 2, which is used to investigate the demodulated datastream di for any bit errors which may have occurred. According to this advantageous refinement of the method according to the invention, an additional interaction method is carried out when big errors are identified, in which incorrectly identified received symbols are corrected and the sum of the carrier-specific error information items $\sum|\Delta\varepsilon 1...n|$ is formed once again using the corrected received symbols. This embodiment variant can be used in particular for modulation methods having a relatively large number of stages.

[0040] According to one further refinement variant of the method according to the invention, only some of the received symbols es1...n derived from the received multicarrier signal ms are used for establishing the correction information ici_{opt}, thus minimizing the complexity for calculating the correction information ici_{opt}, and hence minimizing the delay to the received multicarrier signal ms, that is to say the delay constant $\Delta\tau$.

[0041] According to one advantageous development, the method according to the invention is used together with an error handling routine. In this case, no equalization of the ICI interference in the received multicarrier signal is carried out initially. In a first step, the received multicarrier signal is first of all demodulated, and the demodulated datastream di is then investigated for bit errors, using the error handling routine. Only if bit errors that are identified can no longer be corrected is the method according to the invention carried out, with bit errors that have been identified, that is to say incorrect received symbols es1...n, not being included in the formation of the disturbance-information-specific sum error information items $s\varepsilon 1...4 = \sum|\Delta\varepsilon 1...n|$. This may be done, for example, by masking out the incorrect subcarriers st1...n or received symbols es1...n or by appropriate correction of the faulty received symbols es1...n. This advantageous development can be repeated iteratively until all the ICI interference has been corrected by equalization.

[0042] According to one alternative refinement variant of the method according to the invention, based on the error curve illustrated in Fig. 4, the minimum sum $\underline{s}\varepsilon_{min}$ of the subcarrier-specific error information items $\sum|\Delta\varepsilon 1...n|$ is determined by an iterative search - with a defined step width - using two small reference disturbance information items ici1, 3 or test disturbances.

<u>[0043] While the embodiments disclosed above use wireless radio channels, the invention may also be used with cable-based transmission channels and wire-based transmission channels, as known in the art and mentioned in paragraph [0002].</u>